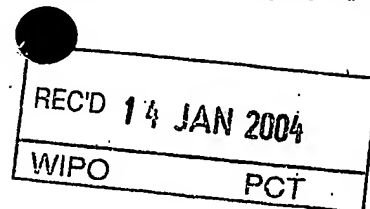




KONGERIKET NORGE  
The Kingdom of Norway

PCT/NO 03/00425



JUN 2005

Bekreftelse på patentsøknad nr  
*Certification of patent application no*

2002 6232

Det bekreftes herved at vedheftede  
dokument er nøyaktig utskrift/kopi av  
ovennevnte søknad, som opprinnelig inngitt  
2002.12.23

*It is hereby certified that the annexed  
document is a true copy of the above-  
mentioned application, as originally filed  
on 2002.12.23.*

2003.12.19

*Line Reum*

Line Reum  
Saksbehandler

**PRIORITY DOCUMENT**  
SUBMITTED OR TRANSMITTED IN  
COMPLIANCE WITH  
RULE 17.1(a) OR (b)



**BEST AVAILABLE COPY**

ld

PATENTSTYRET

02-12-23\*20026232

Applicant: Sinvent AS  
N-7465 Trondheim

Attorney: Svein Hofseth  
Norsk Hydro ASA  
N-0240 Oslo

Inventors: Kåre Aflekt  
Sigurd Einbus veg 3  
N-7036 Trondheim

Armin Hafner  
Veimester Kroghs gate 26B  
N-7052 Trondheim

Arne Jakobsen  
Rådmann Hammers vei 16D  
N-7020 Trondheim

Petter Neksa  
Gløshaugveien 6  
N-7030 Trondheim

Jostein Pettersen  
Johannes Minsaas vei 12  
N-7053 Trondheim

Håvard Rekstad  
Peder Kroghs vei 12  
N-7030 Trondheim

Geir Skaugen  
Dalen Hageby 31  
N-7044 Trondheim

Trond Andresen  
Abelsborg gate 11  
N-7036 Trondheim

Espen Tøndell  
Saturnveien 11  
N-7036 Trondheim

Munan Elgsæther  
Leistadgrenda 5  
N-7047 Trondheim

Title: Method of operation and regulation of a vapour compression system.

**Field of invention**

The present invention relates to a method of operation of a compression refrigeration system including a compressor, a heat rejector, an expansion means and a heat absorber connected in a closed circulation circuit that may operate with supercritical high-side pressure, using carbon dioxide or a mixture containing carbon dioxide as the refrigerant in the system.

**Description of prior art and background of the invention**

Conventional vapour compression systems reject heat by condensation of the refrigerant at subcritical pressure given by the saturation pressure at the given temperature. When using a refrigerant with low critical temperature, for instance CO<sub>2</sub>, the pressure at heat rejection will be supercritical if the temperature of the heat sink is high, for instance higher than the critical temperature of the refrigerant, in order to obtain efficient operation of the system. The cycle of operation will then be transcritical, for instance as known from WO 90/07683. Temperature and the high-pressure side will be independent variables contrary to conventional systems.

WO 94/14016 and WO 97/27437 both describe a simple circuit for realising such a system, in basis comprising a compressor, a heat rejector, an expansion means and an evaporator connected in a closed circuit. CO<sub>2</sub> is the preferred refrigerant for both of them.

The system coefficient of performance (COP) for trans-critical vapour compression systems is strongly affected by the level of the high side pressure. This is thoroughly explained by Skaugen G., Pettersen J., 1994, "*Operation of Trans-Critical CO<sub>2</sub> Vapour compression Circuits in Vehicle Air Conditioning*" Proc. IIR Conf. New Applications of Natural Working Fluids in Refrigeration and Air Conditioning, Hannover, Germany, who also presents a mathematical expression for the optimum pressure. Based on the fact that the high side pressure is independent from temperature, high side pressure can be controlled in order to achieve optimum energy efficiency. The next step is to determine optimum pressure for given operating conditions.

Several publications and patents are published, which suggests different strategies to determine the optimum high side pressure. Inokuty H., 1922, "*Graphical Method of Finding Compression Pressure of CO<sub>2</sub> Refrigerating Machine for Maximum Coefficient of Performance*", IIR Congr., published a graphic method already in 1922, but it is not applicable for the present digital controllers.

EP 0 604 417 B1 describe how different signals can be used as steering parameter for the high side pressure. A suitable signal is the heat rejecter refrigerant outlet temperature. The relation between optimum high side pressure and the signal temperature is calculated in advance or measured. This EP reference describes more or less an analogous strategy. Different signals are used as input parameter to a controller, which based on the signals regulates the pressure to a predetermined level.

Among others, Liao S., Jakobsen A., 1998, "*Optimal Heat Rejection Pressure in Transcritical Carbon Dioxide Air Conditioning and Heat Pump Systems*", Proc. Gustav Lorentzen IIR Conf. Natural Working Fluids, Oslo, Norway, presented an equation, which calculates optimum pressure from theoretical input. The equation does not take into account practical aspects that may affect the optimum pressure significantly.

Most methods for optimum pressure determination described above, has a theoretical approach. This means that they are not able to compensate for practical aspects like varying operating conditions and influence of oil in the system. Optimum pressure will

then most probably be different from the calculated one. There is also a risk for a "wind up" and lack of control. The temperature signal gives a feedback to the controller, which in turn adjusts the pressure with some delay. If conditions change rapidly, the controller will never establish a constant pressure, and cooling capacity will vary.

As explained above, it is a possibility to run tests and measure optimum high side pressure relations. But this is time consuming, expensive. Furthermore, it is hard, if not impossible, to cover all operating conditions. And the measurements have to be performed for all new designs.

#### **Summary of the invention**

A major object of the present invention is to make a simple, efficient method of operating a system that avoids the aforementioned shortcomings and disadvantages.

The invention is characterized by the features as defined in the accompanying independent claim 1.

Advantageous features of the invention are further defined in the accompanying independent claims 2 -7.

The present invention is based on the system described above, comprising at least a compressor, a heat rejecter, an expansion means and a heat absorber. It is a new and novel method for optimum operation of such a system with respect to energy efficiency.

When operating conditions change, the controller in the trans-critical vapour compression system can perform a perturbation of the high side pressure and thereby establish a correlation between the pressure and the energy efficiency, or a suitable parameter reflecting the energy efficiency. A relation between high side pressure and energy efficiency can then easily be mapped, and optimum pressure determined and used until operating conditions change. This is a simple method, which will work for all designs of trans-critical vapour compression systems. No initial measurements have to be made, and practical aspects will be accounted for on site.

### Brief description of the drawings.

The invention will be further described in the following by way of examples only and with reference to the drawings in which,

Fig. 1 illustrates a simple circuit for a vapour compression system.

Fig. 2 shows a temperature entropy diagram for carbon dioxide with an example of a typical trans-critical cycle.

Fig. 3 shows a schematic diagram showing the principle of optimum high side pressure determination. Temperature approach is used as COP reflecting parameter in the figure.

### Detailed description of the invention.

Fig. 1 illustrates a conventional vapour compression system comprising a compressor 1, a heat-rejector 2, an expansion means 3 and a heat absorber 4 connected in a closed circulation system.

Figure 2 shows a trans-critical CO<sub>2</sub> cycle in a temperature entropy diagram. The compression process is indicated as isentropic from state a to b. The refrigerant exit temperature out of the heat rejecter c is regarded as constant. Specific work, specific cooling capacity and coefficient of performance are explained in the figure.

As mentioned above, there is a mathematical expression for high optimum high side pressure in a trans-critical vapour compression system. The expression is as follows:

$$\left( \frac{\partial h_c}{\partial p} \right)_\tau = -\epsilon \left( \frac{\partial h_b}{\partial p} \right)_\tau$$

The optimum pressure is achieved when the marginal increase of capacity (change of  $h_c$  at constant temperature) equals  $\epsilon$  times the marginal increase in work (change of  $h_b$  at constant entropy).

Perturbation of the high side pressure is in principle a practical approach to use the equation above. By mapping the energy efficiency, or a parameter which reflects the energy efficiency, as function of high side pressure, it is possible to establish the point where the marginal increase of capacity equals  $\epsilon$  times the marginal increase in work.

Various parameters can be used as reflection for the energy efficiency.

#### Example 1

The temperature difference between refrigerant and heat sink at the cold end of the heat rejecter 4 is often denoted as "temperature approach" for a trans-critical cycle. There is a correlation between high side pressure and the temperature approach. An increase of the high side pressure will lead to a reduction of temperature approach. The high side pressure can favourably be increased until a further increase does not lead to a significant reduction of temperature approach. At this point, optimum high side pressure is then in practice established, and the system can be operated at optimum conditions, maximizing the system COP. This principle is illustrated in figure 3.

A perturbation of the high side pressure will produce a relation as indicated in figure 3. When operating conditions change, or for other reasons, a new perturbation can be made and a new updated relation established. In this way, the trans-critical system will always be able to operate close to optimum conditions.

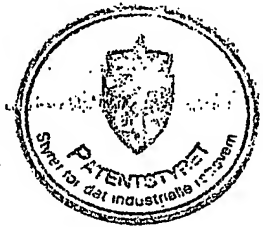
#### Example 2

Instead of using the temperature approach, it is an option to use the gas cooler outlet temperature as parameter for reflection of energy efficiency.

Example 3

By online measurements of system pressures and temperatures, it is possible to automatically calculate the enthalpies for a trans-critical cycle at the points 1 to 4 indicated in figure 2, if the refrigerant properties can be provided from property a library. The enthalpies can be used for calculation of the system coefficient of performance. A perturbation of the high side pressure will then produce a relation between COP and the high side pressure directly.

If COP is used as steering parameter, the optimum high side pressure will be established directly. If a COP reflecting parameter is used, an exact measure for the "marginal effect" on the parameter has to be quantified. This measure can however easily be estimated. Another possibility is to increase pressure until the parameter reaches a predetermined level.

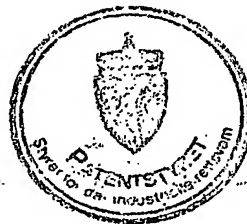




### Claims

1. Method of operation of a compression refrigeration and heat pump system including at least a compressor (1), a heat rejecter (2), an expansion means (3) and a heat absorber (4) connected in a closed circulation circuit that may operate with supercritical high-side pressure, where that carbon dioxide or a refrigerant mixture containing carbon dioxide is applied as the refrigerant in the system, **characterized** in that an online estimation of coefficient of performance (COP), or a parameter reflecting the COP, is used as a signal for optimum regulation and operation of the compression refrigeration system.
2. System according to any of the preceding claims 1-4, **characterized** in that a regulation system may vary pressure on the high pressure side in order to map the COP or the COP reflecting parameter as a function of pressure for a given operation condition.
3. System according to any of the preceding claims 1-2, **characterized** in that the temperature difference between the refrigerant and heat sink at the cold end (temperature approach) is used as a signal for optimum regulation and operation of the compression refrigeration system.
4. System according to any of the preceding claims 1-3, **characterized** in that pressure on the high pressure side of the system is increased until the increase has marginal effect on the temperature approach.
5. System according to any of the preceding claims 1-4, **characterized** in that pressure on the high pressure side of the system is increased until temperature approach is equal or lower than a predetermined level.

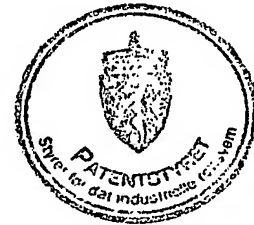
6. System according to the preceding claim 5,  
**characterized** in that the predetermined level may vary with varying operation conditions.
7. System according to the preceding claims 1-6,  
**characterized** in that the heat rejecter outlet temperature is used as COP reflecting parameter.



### Abstract

Method of operation and regulation of a compression refrigeration and heat pump system, including at least a compressor (1), a heat rejecter (2), an expansion means (3) and a heat absorber (4) connected in a closed circulation circuit that may operate with supercritical high-side pressure. Carbon dioxide or a refrigerant mixture containing carbon dioxide is applied as the refrigerant in the system.

An online estimation of coefficient of performance (COP), or a parameter reflecting the COP, is used as a signal for optimum regulation and operation of the compression system.



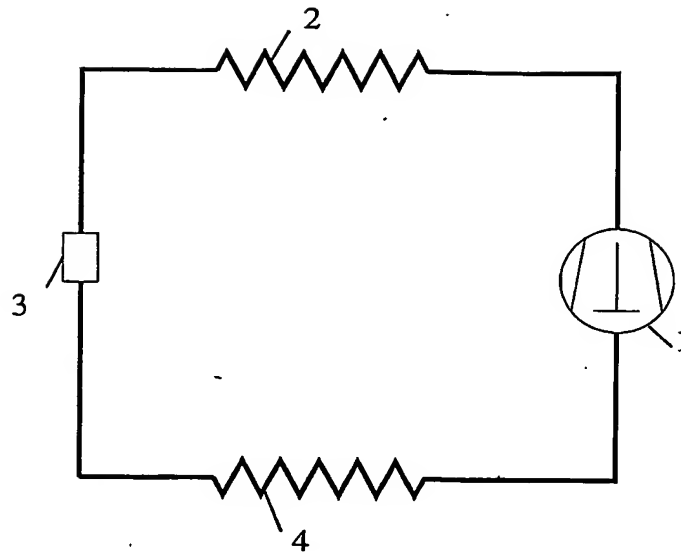


Fig. 1

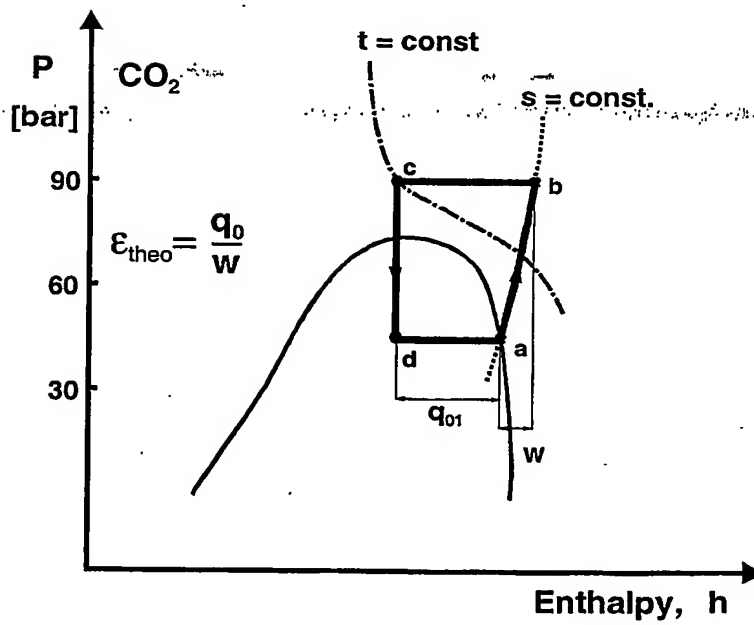


Fig. 2



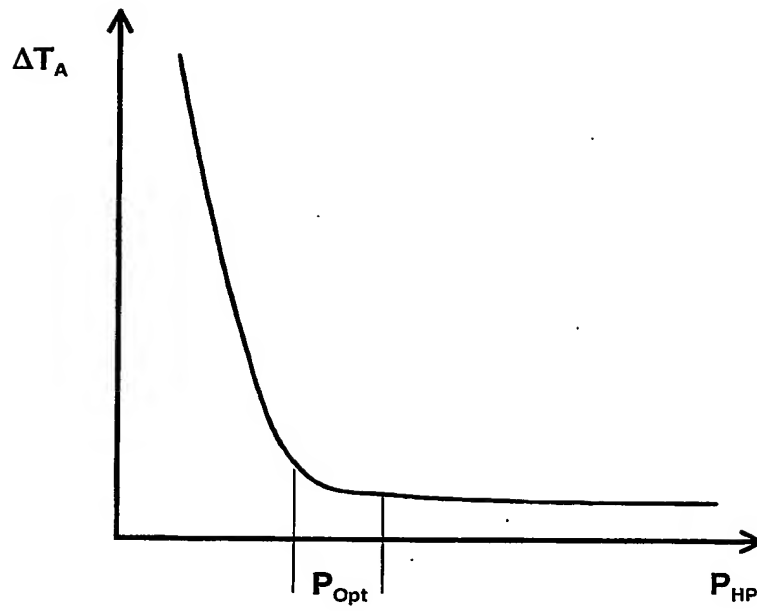
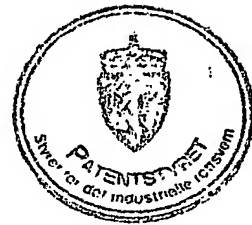


Fig. 3



**This Page is Inserted by IFW Indexing and Scanning  
Operations and is not part of the Official Record**

**BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

☐ **BLACK BORDERS**

☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**

☐ **FADED TEXT OR DRAWING**

☐ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**

☐ **SKEWED/SLANTED IMAGES**

☐ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**

☐ **GRAY SCALE DOCUMENTS**

☒ **LINES OR MARKS ON ORIGINAL DOCUMENT**

☒ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**

☐ **OTHER:** \_\_\_\_\_

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.**